Study on a Floating Nuclear Power Plant

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1. INTRODUCTION

The global greenhouse effect is one of the most serious difficulties for human beings in the 21st century and there is a fear of its aggravation due to explosive increase in population and economic growth in under developing countries. It is required for controlling the effect to use more energy resources with less emission of carbon dioxide. The expansive utilization of nuclear energy is the most economical and realistic solution. It is, however, not expectable to construct many new power reactors in Japan due to the lack of the appropriate new sites for them. Offshore siting is considered to be one of the most promising technologies. The offshore siting methods are classified into three types: a floating type, a settled type and a land reclamation type. We are most interested in floating type among them, since a lot of excellent research works had been pursued recently on technologies for constructing a large floating platform. Offshore floating siting has some advantages of supplying electricity close to it's consumer, of reducing enviromental impact on land, of moderating the seismic load on nuclear power plant and of providing enough cooling water.

There have been some projects on a floating nuclear power plant (FNPP) so far. The Atlantic Generating Station (AGS) plan was the most closed to realization among them. The detail design information on AGS is described in the report from Daniel, Mann, Johnson & Mendenhall(1). The AGS is offshore nuclear power station and has two floating platforms enveloped with a breakwater. A large PWR is installed on each platform. US-Nuclear Regulatory Committee (USNRC) permitted the AGS construction in 1982. The project, however, was abandoned due to decrease in electricity demand brought by the first oil-shock. The Pevek project (2) is now existing but not so active due to financial difficulties in Russia. Small power reactors will be installed on a barge, which will be moored at the pier at Pevek in the east Siberia.

Although there are some design studies as mentioned above, Japan Atomic Energy Research Institute (JAERI) studied the technical feasibility of the FNPP in Japan from 1995 to 1998, since the thought of nuclear safety is not always equal in the world.

We studied mainly how to consider the safety of the FNPP in Japan. The technical requirements for the FNPP were also studied.

2. THE SAFETY OF FNPP

(1) The FNPP Concept

The FNPP is a system composed of a nuclear power plant, a floating platform with mooring equipment, a breakwater to provide calm sea basin and equipment for access to maintain the FNPP, as shown in Fig.1. The FNPP is installed on the coast, of which depth must be less than 20m to construct a breakwater economically. The distance from the FNPP to the shore should be greater than about 1km to keep adequate isolation from the public and be smaller than about 2km to have the good accessibility. The floating platform is moored with mooring equipment in the basin enveloped with a breakwater. The width of the floating platform should be about 80m or less to be constructed in a dockyard and its length should be determined to provide enough area for installation of a nuclear power plant.

(2) The Safety Design of the FNPP

The FNPP is a nuclear plant based on a floating platform. Therefore, the function of the platform is equal to that of the ground for a land based nuclear power plant, that is, to support a nuclear power plant stable. Then the safety design of the FNPP should be the stability design of the floating platform and the safety design of the nuclear plant on it, which should be fundamentally equal to that of an existing nuclear power plant. Then, the stability of a floating platform is the essential issue for the FNPP safety.

In the case of an existing nuclear power plant, the stability of the ground is mainly discussed in an earthquake. On the other hand, many kinds of natural phenomena should be considered in the case of the FNPP. They are winds, ocean waves, earthquakes, seaquakes, tsunami and storm surges. These phenomena could be divided into two groups. Heavy winds, ocean waves and storm surges could be brought by heavy storms, while earthquakes, seaquakes and tsunami by earthquakes.

There is stochastic philosophy in the seismic design of an existing nuclear power plant. For instance, a nuclear power plant in normal operation should be robust with additional seismic load brought by a very large earthquake of which occurrence frequency is very small. While, smaller earthquake is enough for the evaluation of the robustness of a nuclear power plant in an accident state, since its occurrence frequency is also very small. The other feature of the seismic design of an existing nuclear power plant is classification of facilities of which a nuclear power plant is composed. They are classified according to their importance in assuring nuclear safety. The structural soundness of the most important facilities has to be maintained in the S1 earthquake, which is defined as a larger earthquake than any other earthquakes that have ever occurred at the site. Moreover, the safety functions of the most important facilities has to be maintained in the S2 earthquake, which is defined as the largest earthquake among earthquakes supposed to be possible at the site from the engineering consideration. Therefore, the S1 and the S2 storms should be considered in the evaluation of the stability of a floating platform. There are, however, difficulties to determine such storms. It is one of the reasons that the meteorological observations started only 50 or 100 years ago in Japan to increase ambiguity in the estimation of the S1 storm, if we adopt its occurrence frequency as same as that of S1 earthquake (about 10^{-3}/year). Although historical earthquakes have been studied extensively through ancient manuscripts, very few studies have been executed on historical storms. Large earthquakes often leave the traces as dislocations, while heavy storms do not leave such clear marks. Our conclusion is that it is one of key technical subjects to realize the FNPP to study storms extensively enough to determine the S1 and S2 storms.

It should be also pointed out that we have to consider the possibility of the simultaneous occurrence of a heavy earthquake and a heavy storm with stochastic consideration including the difference in the duration. In general, the duration of a storm is from a few hours to a few days, while that of an earthquake is less than one minute.

3. CONCEPTUAL DESIGN OF THE FNPP

(1) Outline of the Design

In order to study the feasibility of the FNPP in detail, JAERI made a conceptual design of the FNPP. A large light water cooled reactor plant of 1,000 MWe is considered in the design. The required area to construct the plant is determined to be 16,000m^2 which is the same as that of the existing power plant and the total weight of the plant is determined to be 250,000t which is almost one third of the existing power plant. We have to make a reactor power plant more light weight to install it on a floating platform, and it should be possible by replacing concrete structure to steel.

A floating platform is determined to be double hull structure and to accord with two-compartment standard of subdivision. Its major dimensions are calculated considering wave height of 1m as shown in Table 1. The width is 80m, the length 300m to provide enough area, the depth 35m, the draught 12.4m, the displacement about 300,000t. The heal and trim are calculated to be less than 0.94 degrees and 0.25 degrees respectively in the case of flooding into two compartments of subdivision.

We determined to adopt guide frame – fender type as mooring equipment because of its good performance in an earthquake and a tsunami. Number of mooring equipment are determined by evaluated mooring force based on strong wind (70m/sec) and calm wave (significant wave height of 1m) provided by a breakwater.

A breakwater is designed to make wave height in the basin less than 1m even in the case of very rough sea with significant wave height of 10 m, which has a reproduce period of 100 years in Japanese waters. Cross section of the breakwater is shown in Fig.2. Figure 3 shows a bird-eye view of the conceptual design mentioned above.

(2) Evaluation of the Stability of the Platform

A dynamic movement of a platform was evaluated with a simulation as shown in Fig.4. In the simulation, the natural conditions should be created in the beginning. The significant wave height of about 10m is supposed to be reproduced once a hundred years on the basis of the observed data (3) in Japanese waters. Therefore, we determined 15 m as the severest significant wave height for the simulation. The significant wave period is assumed 14 sec, a general period of gravitational waves. Wind is treated in the simulation to be composed of an average wind and a fluctuating wind. We determined 70 m/sec as the severest wind velocity since the maximum observed wind velocity is 66.7 m/sec in Japan (at Muroto in 1961). A fluctuating wind is calculated with Davemport spectrum for winds and treated as time series data in the simulation.

A calculation model is shown in Fig.5. The nuclear power plant and the floating platform are treated as a rigid rectangular parallelepiped in the model. Mooring equipment is treated as spring system. Waves crossing and penetrating the breakwater and diffracted by it are considered to calculate wave height in the basin. The movement of the platform is calculated by the method developed by Osawa (4).

Simulation results show that the maximum wave height in the basin is 1.2 m and that the maximum trim and heal is less than 0.1 degrees. The maximum inclination of 2 degrees is permitted in the AGS project mentioned above, so the concept is considered safe enough to be operated.

4. CONCLUSIONS

The technical feasibility of the floating nuclear power plant (FNPP) in Japan was studied. It was studied mainly how to consider the safety of the FNPP in Japan. It is pointed out that it is one of key technical subjects in order to realize the FNPP to study storms extensively enough to determine the design base storms.

One design concept of the FNPP was proposed and its safety was evaluated to be enough.

ACKNOWLEDGEMENT

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Table 1 Principal Particulars of a floating platform

Length	300 m
Width	80 m
Depth	35 m
Draft	0.85 m
Displacement	305,000 ton

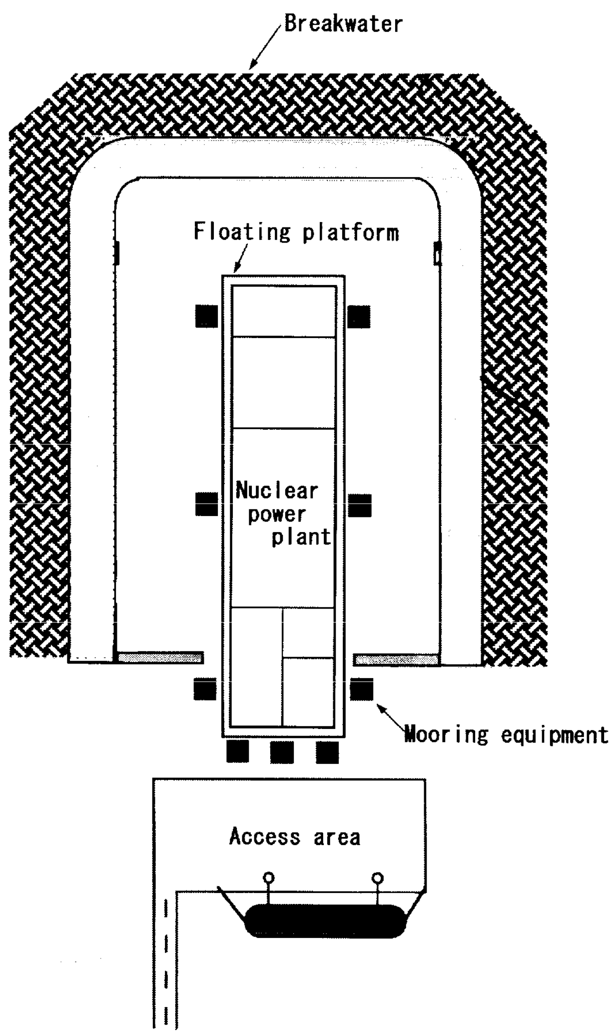

Fig. 1 Layout of FNPP

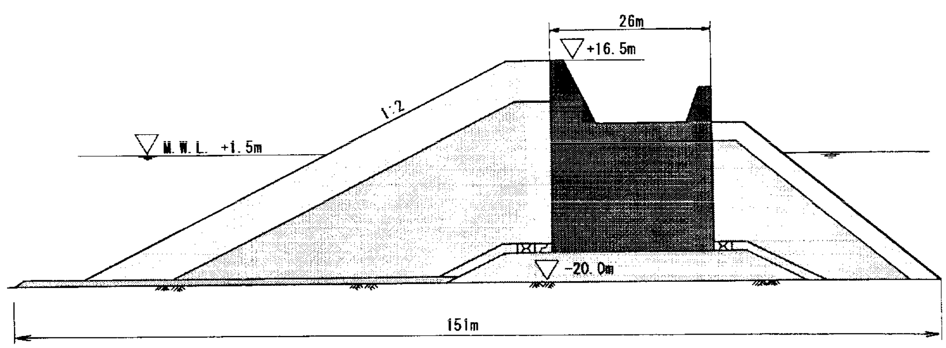

Fig. 2 Cross section of the breakwater

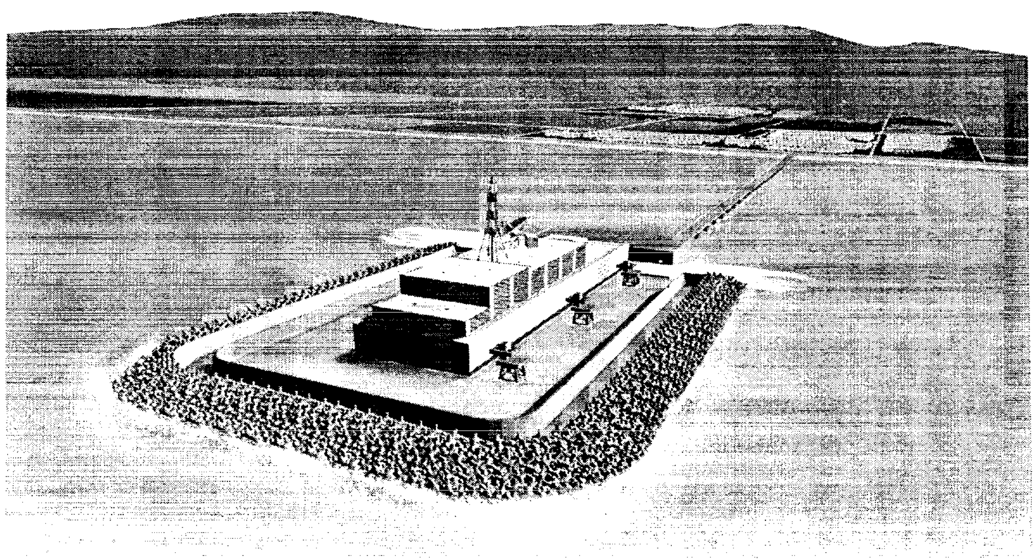

Fig. 3 A bird-eye view of the FNPP

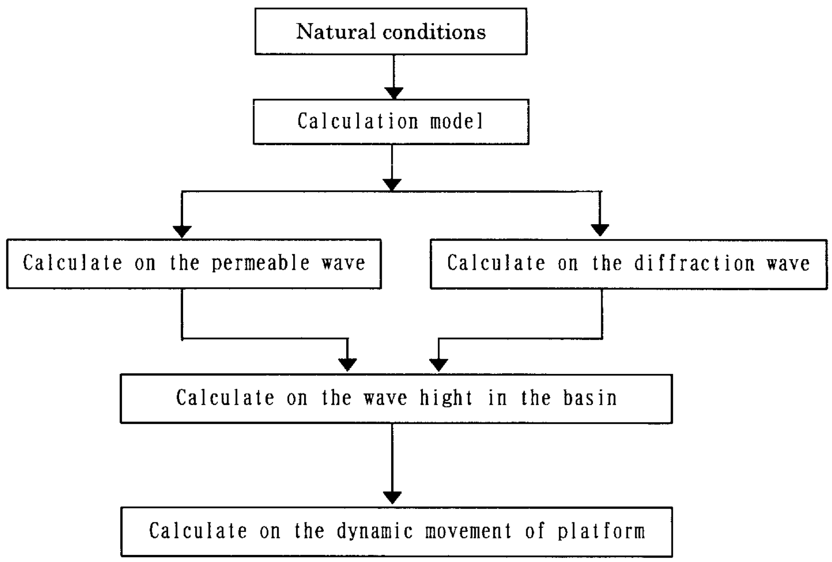

Fig.4 Simulation

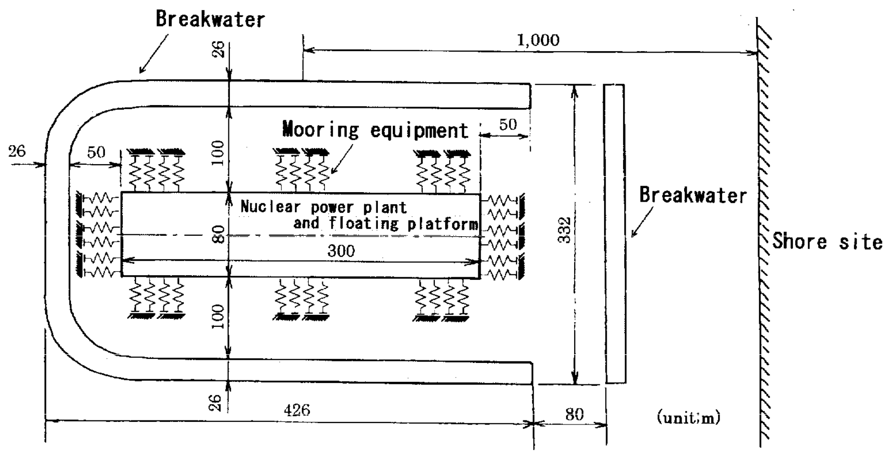

Fig.5 A calculation model of the FNPP